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STIMULUS DETERMINANTS OF DYNAMIC VISUAL ACUITY
III. Effects of Proximal Borders and Limited Surround

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SUMMARY PAGE

THE PROBLEM

Tests of dynamic visual acuity (DVA) appear to offer unique potential for assessing practical visual capabilities. These tests have not been standardized with respect to variations in the target surround, nor are the effects of such variations understood. Goodson and Morrison have demonstrated the ease with which the DVA function may be accelerated (increased degradation as a function of target velocity) by limiting the size of the target surround. According to their acquisition hypothesis, the DVA function should be decelerated by surrounding the target with a border. The problem is to determine whether DVA performance may be degraded or enhanced by such manipulations of stimuli surrounding the acuity target.

FINDINGS

The present experiments demonstrated that relatively simple modifications of the stimulus configuration in the target surround can affect significantly an individual's DVA performance. However, not all subjects responded to modifications of the target surround in the same manner. Implications regarding individual differences versus practice and order effects are discussed.

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INTRODUCTION

The ability to recognize a moving target during voluntary ocular pursuit is degraded as a function of the target's angular velocity with respect to the observer (1). The measure of acuity thresholds as a function of target angular velocity is called Dynamic Visual Acuity (DVA). It is thought that the DVA function reflects characteristics of the visual and oculomotor systems which are of critical importance in the performance of operational aviation missions, and that the assessment of DVA abilities of naval aviation personnel will be of value for both diagnostic and predictive purposes (2). However, techniques for obtaining DVA measures have not been standardized, nor are there sufficient data upon which to base the definitions of standard apparatus and procedures for assessing DVA.

Both DVA and static visual acuity are measured in terms of recognition thresholds for acuity targets. However, the relationship between the two is not well understood. Although there is some dispute regarding the correlation between DVA and static acuity performance, it appears that any correlation between the two is decreased when using higher DVA target velocities, monocular viewing conditions, shorter exposure times, and fixed head position (3-6). Large individual differences in DVA are observed among subjects whose static visual acuities are similar (1, 2, 7, 8), and the relative performance among subjects at low target velocities may be reversed at higher velocities (7).

It may be argued that the acquisition abilities required for detection and visual pursuit of the DVA target vary independently of the abilities required for the recognition of critical detail in the target. To the extent that the visual mechanisms responsible for acquisition performance are different from those responsible for recognition, it is expected that the adequate stimulus for acquisition has properties which differ from those of the adequate stimulus for recognition. If that is the case, then variations in the configuration of the DVA stimulus can differentially affect acquisition versus recognition performance, and can thereby affect characteristics of the DVA function.

Goodson and Morrison (9) have shown that the rate of degradation of DVA as a function of target velocity may be increased by limiting the illuminated area surrounding the target. Those results demonstrate the ease with which the DVA function may be modified by altering characteristics of the target surround. However, they do not force the conclusion that the acquisition response was altered independently of the recognition response, since it is already well known that static acuity performance may be degraded both by reducing the luminance of the stimulus field surrounding the target area (10, 11) and by presenting the target at luminance levels which differ from pre-exposure levels to which the subject is adapted (12, 13). It appears that a critical test of the acquisition hypothesis will require that the acquisition cues have little or no effect upon static visual acuity, or that they affect static visual acuity and DVA performance in opposite directions.

It is proposed that this requirement may be met by the placement of additional contours around the DVA target. By the acquisition hypothesis, the resulting increase in size of the moving stimulus pattern would enhance its stimulus properties for detection and pursuit, but would not enhance the resolution of the acuity target contained within it.

Some evidence is available upon which to base the prediction of enhanced acquisition performance. Although the relationship between target size and detectability for rapidly moving targets has not been defined, the detectability (luminance threshold) of a stationary target is known to be dependent upon target size (14-16), at least for sizes up to and exceeding 10° angular subtense. Further, there is a linear relationship between target speed and luminance threshold for detecting the presence of a rapidly moving target (17), and a separate, diverging linear relationship between target speed and luminance threshold for discriminating the direction of target movement (18-20). Discrimination of the presence of the target and its direction of movement are presumably two important components of the acquisition process required by the DVA task.

The prediction of either a neutral or negative effect upon recognition performance is based upon the following. The ability to perceive a minimal target stimulus can be degraded by the presence of a visible, proximal border (21, 22). The degree of interference by the proximal stimulus increases to a maximum, and then decreases, as its distance from the target is decreased. This has been demonstrated for the detection of a small disc near a bar (23), detection of a line between two dark bars (24), acuity for a Landolt ring surrounded by four dark bars (25), and acuity for a vernier target placed between two lines oriented either parallel or perpendicular to the target (26).

Thus, it appears that the placement of a dark annulus or rectangular border around a DVA target should affect target recognition either negatively or not at all, and should affect target acquisition (detection and pursuit) positively. Under the assumption that the major source of degradation in the DVA function is related to visual acquisition, it is predicted that the effect of such proximal borders will be to reduce the rate of degradation of DVA as a function of target velocity.

The purpose of this paper is to report two sets of data related to the acquisition hypothesis. The first experiment is exploratory in nature, and seeks to provide comparisons among the effects of two configurations of restricted target surrounds and two similar configurations of dark borders surrounding the target. In the second experiment, the effects of restricting the luminance surround to a circular disc of one foot diameter are compared to the effects of surrounding the target with a dark annular border of similar dimensions.

METHOD

APPARATUS

Subjects viewed Landolt ring targets monocularly through a plane, front surface mirror 10.2 cm high and 25.4 cm wide which rotated in a counterclockwise direction about a vertical axis along its midline. The mirror was driven by a variable speed motor to provide desired angular rates. Target exposure was controlled by a rectangular aperture in a flat white mask attached to the mirror. The aperture height was 2.54 cm. Its width was defined empirically to allow 0.4-sec target exposure for each angular velocity. The distance from center of rotation of the mirror to the eye was 19.5 cm, and to the target was 590.1 cm. The eye to mirror to target angle was 105°. The plane of incidence was perpendicular to the axis of mirror rotation. With this geometry, the mean angular speed of the target image with respect to the eye is 1.94 times the speed of mirror rotation (27).

Targets were presented against a seamless, white, cylindrical background screen of 590.1 cm radius, 75.3° azimuth, and 274 cm height. The center of the screen's curvature was coincident with the axis of rotation of the mirror. The geometry of the room limited the arc size of this screen. A supplementary, flat screen slightly overlapped the right edge of the cylindrical screen to extend the white background an additional 40° in azimuth. The near edge of the flat screen was 376 cm from the mirror. A circular hole of 19 cm diameter was cut in the cylindrical screen for target presentation. The center of the hole was 120 cm from the floor and 34.6° from the edge of the flat screen. A target holder was located directly behind the aperture. With a target in position flush against the back surface of the screen, the aperture was filled.

Counterclockwise rotation of the mirror produced image movement from right to left. Under full screen illumination, the rotating mirror reflected a perceptually uniform surface over 116.3° visual angle, except for a faint vertical line at 41° and the target at 76.6° from the right edge.

A series of Landolt ring targets was produced on matte photographic print paper and mounted on fiberboard discs of 20.3 cm diameter. Target contrast ratio (C) was -0.91. ($C = \frac{L_T - L_B}{L_B}$ where L_T = target luminance and L_B = surround luminance). The series included 18 gap sizes ranging from 0.65 to 20.38 minutes of arc at a viewing distance of 609.6 cm.

The first experiment employed five variations in target surround conditions. In three of these conditions (SA-1 through SA-3), the configurations of the illuminated area surrounding the acuity target were varied. In two of the conditions (B-1 and B-2), the full screen was illuminated (as in SA-1), and one of two dark borders was placed around the target. For SA-1, full screen illumination was provided by 750-watt tungsten lamps mounted in Berkey-Colortran broad flood luminaires. Intensities were adjusted by means of crossed polarizing sheets to produce a near uniform luminance level of 150.7 cd/m^2 (44 ftL) over 40° surrounding the target, with a fall off of 10 percent over the peripheral extent of the screen. For the remaining two luminance configurations (SA-2, SA-3), a Kodak projector was employed to project areal images on the screen so that the target appeared at their center. SA-2 was a circular disc of 30.5 cm (1 ft) diameter, subtending 2°52' visual angle. SA-3 was a rectangle

121.9 cm (4 ft) wide and 61.0 cm (2 ft) high, which subtended 11°25' by 5°43'. In each condition, luminance was controlled by cross polarizing filters to produce near uniform luminance of 150.7 cd/m^2 (44 ftL). Under these limited surround conditions, the only illumination on the remainder of the screen was due to stray light, and provided luminances less than 0.1 cd/m^2. In one border condition (B-1), the target was surrounded by a dark annulus whose inside diameter was 30.5 cm (1 ft), subtending 2°52' visual angle, and whose stroke width was 7.6 cm, subtending 43' visual angle. In the second border condition (B-2), the target was surrounded by a dark rectangular frame of similar stroke width whose inside dimensions were 121.9 cm (4 ft) horizontally and 61.0 cm (2 ft) vertically, subtending 11°25' by 5°43'. In both border conditions, the illumination was the same as that provided for the full screen surround condition (SA-1).

PROCEDURE

Prior to each experimental session, the mirror drive was set for the proper speed, and the appropriate mirror aperture was installed to control exposure time of the target at 400 msec. Within any experimental session, target velocity and luminance condition remained constant.

All observers viewed the target with their right eye, their left eye being occluded by an eye patch. Observers were seated, and their eye position was aligned with respect to the mirror and target by use of an adjustable head and chin rest. The experimenter was stationed behind the screen in order to manage the targets. For each target presentation, the experimenter selected the target of appropriate size and placed it in position with the gap in one of eight orientations. Target orientation was determined from a partially random table. The observer made a forced choice verbal response corresponding to one of eight possible gap orientations. An up-and-down psychophysical method was employed in which the target size was increased after an incorrect response and decreased after a correct response. The size for which an incorrect response followed a correct response was used as an estimate of threshold.

EXPERIMENT 1

Previous experiments have demonstrated that DVA performance may be degraded by limiting the size of the illuminated area surrounding the acuity target (9) and have suggested that the magnitude of this effect is related roughly to the extent to which the illuminated surround is restricted along the dimension of target movement (2). It was suggested in the introduction of this paper that the opposite effect may result when a dark border is placed around the acuity target in an extended field. The purpose of this experiment is to provide exploratory data regarding the effects of a dark border versus limited luminous surround upon DVA performance.

PROCEDURE

Two male subjects between 24 and 26 years participated in this experiment. One subject (JB) demonstrated 20/20 static visual acuity without correction. The second subject (SG) demonstrated 20/30 static acuity without correction, and 20/20 static acuity with correction. He wore corrective spectacles during the DVA tests.

After a brief series of demonstration trials, DVA thresholds were obtained under each of the surround conditions in the following order: SA-2, SA-3, B-1, B-2, and SA-1. For each surround condition, thresholds were obtained first for a target velocity of 20°/sec, then for 124°/sec. Five thresholds were obtained at 20°/sec for each surround condition. Ten thresholds were obtained at 124°/sec for each condition, but only the last five of these ten were included in analyses.

RESULTS

Means and standard deviations were calculated for the last five thresholds obtained for each subject under each condition. These are presented in Table I. Means and 95 percent confidence intervals for each subject are presented graphically in Figure 1.

In general, the order of means for these data is in agreement with earlier observations (9) that DVA performance is degraded by limiting the size of the target surround, and with the proposition that a surrounding border serves to enhance DVA performance. However, the data for Subject JB do not indicate that

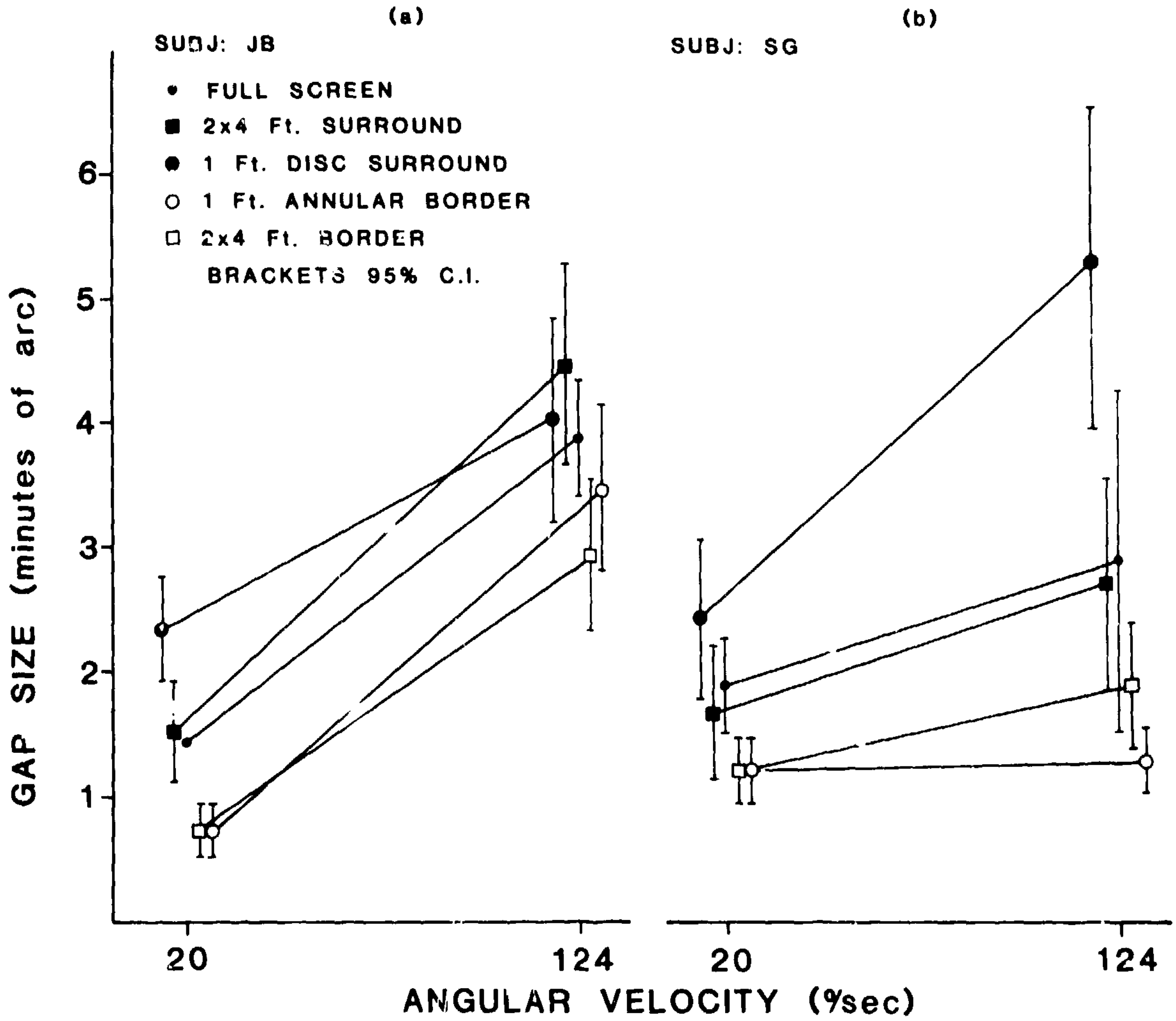

Figure 1. DVA of two subjects for four target surrounds. • = full screen (SA-1). ● = 2°52' disc surround (SA-2). ■ = 11°25' by 5°43' rectangular surround (SA-3). ○ = 2°52' annular border (B-1). □ = 11°25' by 5°43' rectangular border (B-2). Luminance (L) = 150.7 cd/m^2. Contrast ratio (C) = -0.91. Brackets indicate 95% confidence intervals (C.I.).

EXPERIMENT 2

The exploratory data reported in the previous section suggest that a smaller circular surround configuration (SA-2, B-1) is more effective than a larger configuration (SA-3, B-2) in modifying DVA performance. Therefore, the circular disc and the annular border were chosen to be employed as experimental surround conditions in the present experiment.

The purpose of the present experiment is to test hypotheses of no difference in DVA performance when the target is presented in a large luminous surround (SA-1) versus a limited surround (SA-2) versus being surrounded by an annular border (B-1).

PROCEDURE

Five male subjects between 20 and 26 years participated in this experiment. All subjects demonstrated 20/20 static visual acuity without correction.

The experiment employed two target velocities, 20°/sec and 124°/sec, and three surround conditions, SA-1 (full screen), SA-2 (disc surround), and B-1 (annular border). For each surround condition, thresholds were obtained first for a target velocity of 20°/sec, then for 124°/sec. The order in which surround conditions were employed for three of the five subjects (WJ, DW, SJ) was SA-1, B-1, and SA-2. The order was reversed for the two remaining subjects (SA, WC). Since the detrimental effect of limiting the luminous surround (SA-2) had been demonstrated already (9), the surround condition of primary concern in this experiment was the annular border (B-1). This condition was always presented second in order never to allow the benefit of practice over two prior sessions.

After a brief explanation and demonstration of the DVA task, five thresholds were obtained at 20°/sec for each surround condition. Then, ten thresholds were obtained for each surround condition at 124°/sec. Only the last five of those ten thresholds were included in analyses, the preceding trials being counted as practice.

RESULTS

Means and standard deviations were calculated for the last five thresholds obtained for each subject under each condition. These are presented in Table II.

Group means are presented graphically in Figure 2. Means and 95 percent confidence intervals for each subject are presented graphically in Figure 3.

As was the case in Experiment 1, the order of the means presented in Figure 2 is consonant with the proposition that DVA performance is degraded by restricting the size of the target surround and enhanced by surrounding the target with an annular border. Relative to the full screen condition, the DVA function appears to diverge upward (increased rate of degradation) for the limited surround condition and downward (decreased rate of degradation) for the annulus surround condition.

However, a 2 x 3 analysis of variance with repeated measures on each factor did not confirm statistical significance for this Velocity-by-Surround interaction.

Table II

Effects of Target Surround Upon DVA.

Means and Standard Deviations of DVA Thresholds (n=5)

for Each of Five Subjects

	Angular Velocity					
	20°/sec			124°/sec		
	Surround			Surround		
Subject	SA-1	B-1	SA-2	SA-1	B-1	SA-2
WJ	1.83 (0.27)	1.21 (0.36)	0.89 (0.22)	3.18 (0.94)	1.67 (0.80)	2.35 (0.34)
SA	1.21 (0.45)	0.89 (0.22)	1.60 (0.21)	0.81 (0.22)	1.29 (0.36)	3.09 (1.20)
DW	1.13 (0.33)	0.73 (0.18)	1.12 (0.64)	2.13 (0.50)	1.52 (0.33)	2.97 (0.88)
SJ	1.90 (0.17)	1.21 (0.45)	1.90 (0.31)	5.15 (1.18)	3.08 (0.75)	5.23 (0.77)
WC	1.05 (0)	1.05 (0)	1.13 (0.18)	2.66 (0.42)	1.44 (0.47)	7.00 (0.76)

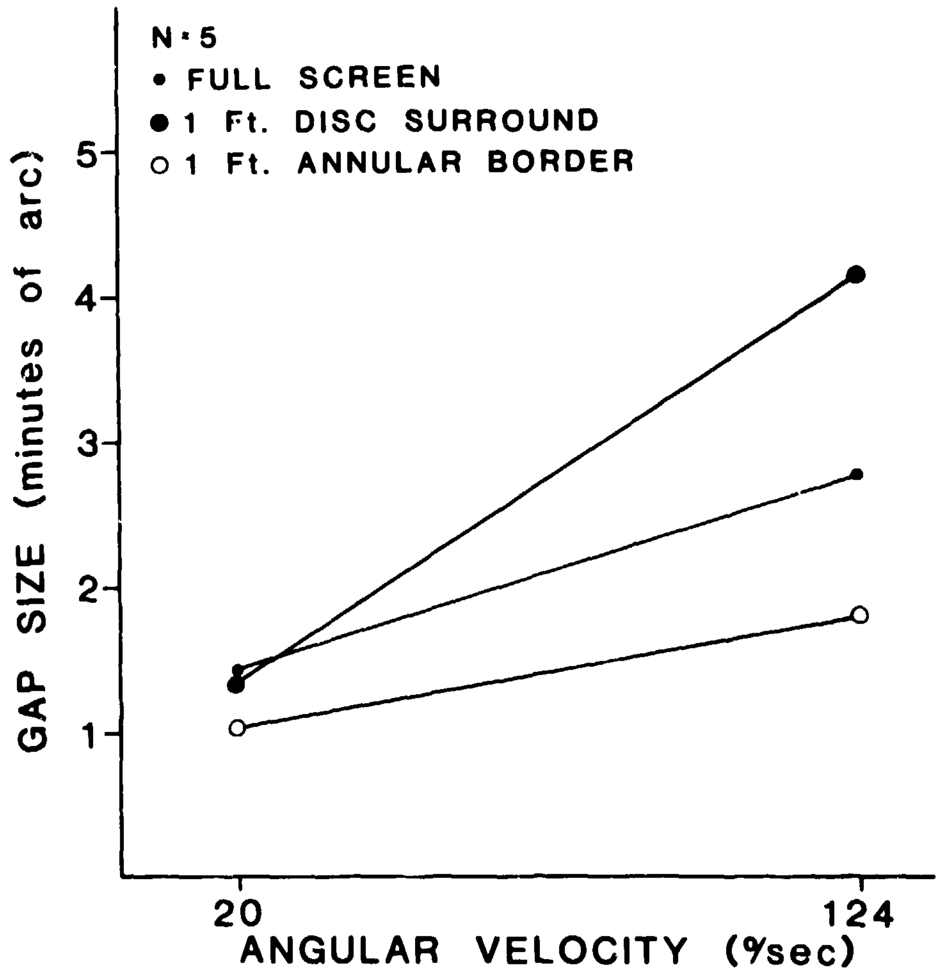

Figure 2. Mean DVA performance of five subjects for three target surrounds. • = full screen (SA-1). ● = 2°52' disc surround (SA-2). ○ = 2°52' annular border (B-1). Luminance (L) = 150.7 cd/m^2. Contrast ratio (C) = -0.91.

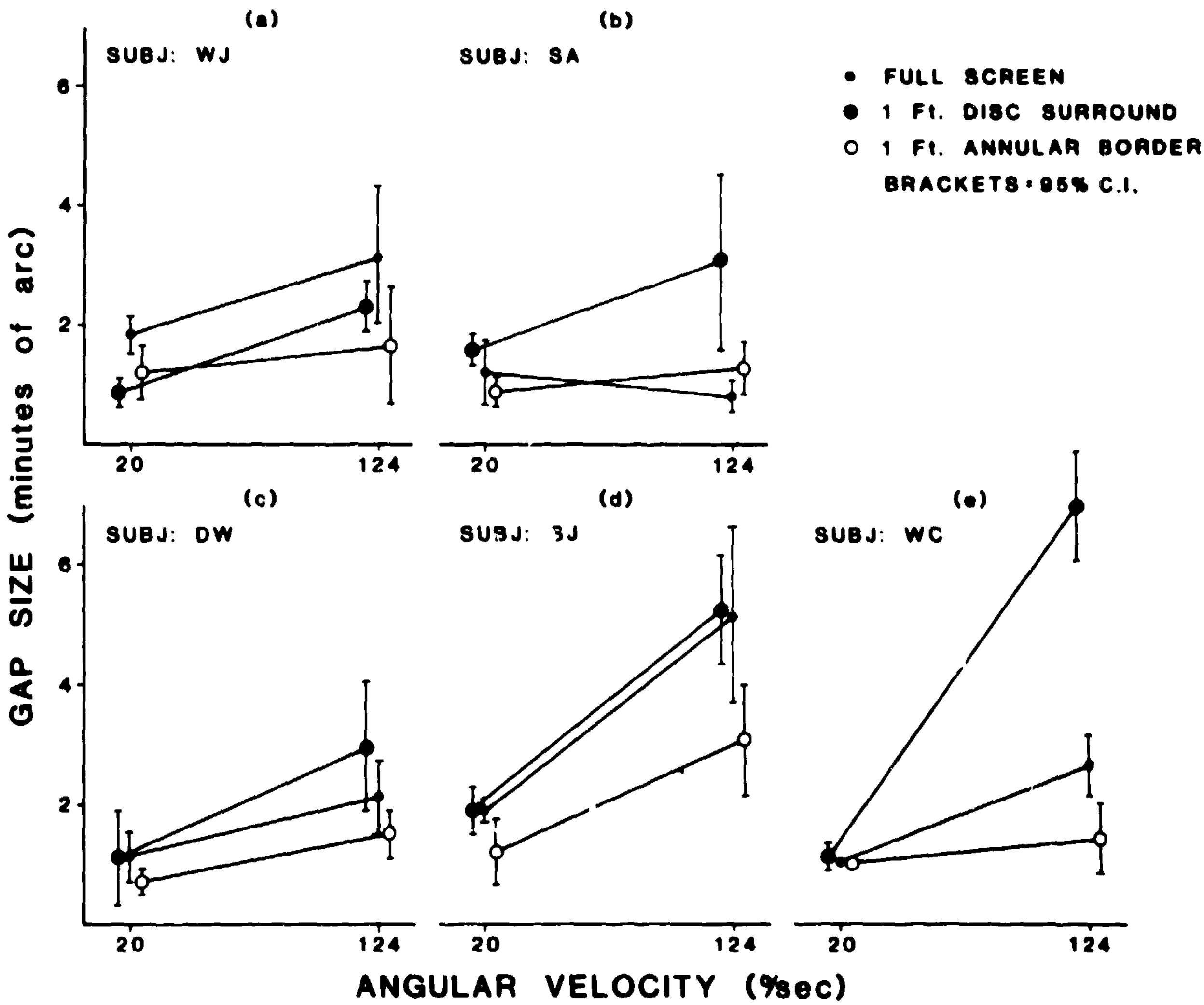

Figure 3. DVA of five subjects for three surround conditions. • = full screen (SA-1). ● = 2°52' disc surround (SA-2). ○ = 2°52' annular border (B-1). Luminance (L) = 150.7 cd/m^2. Contrast ratio (C) = -0.91.

Variations in performance among individual subjects are apparent from the graphs of Figure 3. The expected effects of the surround conditions are demonstrated clearly for Subject WC in Figure 3(e). DVA performance at 20°/sec was about equal for all surround conditions. At 124°/sec, the degradation in DVA was greater under the full screen condition (SA-1) than under the annulus condition (B-1), and greater under the limited surround condition (SA-2) than under the full screen condition (SA-1). Similar effects are marginally apparent in the graph for Subject DW, Figure 3(c).

For each of the remaining three subjects, one of the expected interactions is evident, but not both. Subjects WJ and SJ appear to have exhibited an enhancement effect under the annulus surround condition (B-1), but not a degradation effect when the limited surround (SA-2) was employed. The degradation effect of the limited surround is apparent for Subject SA, but no enhancement due to the annulus is apparent.

DISCUSSION

It is well known that the ability to recognize a moving target is degraded as a function of the target's angular velocity with respect to the observer (28). Ludvigh (29) and Ludvigh and Miller (1) have argued that this degradation is due primarily to a mismatch between eye pursuit velocity and target velocity, resulting in image movement on the retina.

It has been suggested by Goodson and Morrison (9), and in the present paper, that the acquisition responses required for the maintenance of a stable image of a moving target on the retina may be limited by visual mechanisms that are different from those which limit static visual acuity. It was further suggested that the adequate stimulus for visual acquisition may possess characteristics which are independent of the adequate stimulus for visual resolution and that the DVA function might, therefore, be modified by manipulating such characteristics in the stimulus configuration surrounding the acuity target. This proposal was supported, in part, by the observation that DVA performance is degraded more severely as a function of target velocity when the luminous field surrounding the target is limited in size than when the target is presented against a large, uniform field (9).

The purposes of the present experiments were to reproduce the finding that the DVA function is accelerated by limiting the target surround, and to test the proposition that the DVA function would be decelerated by surrounding the acuity target with a border. Both effects were exhibited clearly by one of two subjects (SG) in Experiment 1, and by one of five subjects (WC) in Experiment 2. They were marginally apparent for a second subject (DW) in Experiment 2. Of the remaining three subjects, two (SJ, WJ) appear to exhibit an enhancement effect due to the border, and one (SA) appears to exhibit a degradation effect due to the limited target surround. However, the _a priori_ analyses of the group data did not confirm statistical significance for the predicted interactions between the full screen (SA-1) and limited surround (SA-2) conditions, or between the full screen (SA-1) and annular border (B-1) conditions.

It is likely that three uncontrolled factors contributed to this result: individual differences, practice effects, and order effects. Large individual differences have been demonstrated in the rate at which visual acuity is degraded as a function of target velocity (2, 8). Some subjects show no degradation in acuity even for target velocities exceeding 100°/sec. Subject SA (Figure 3(b)) appears to have suffered no degradation at 124°/sec under the full screen condition (SA-1). One could not expect that the introduction of the annular border would benefit DVA performance if no degradation had occurred under the full screen condition. It may be that future experiments of this nature should employ screening procedures for subjects, requiring the demonstration of a significant change in performance as a function of target velocity under the standard full screen condition.

The effects of practice and order of experimental conditions are more elusive for _post facto_ inquiry. Goodson and Morrison (9) have suggested that improvement of DVA performance with practice continues over a larger number of trials than was previously thought (8, 30, 31), and that practice under the more favorable condition of full screen illumination serves to reduce the degradation observed under the less favorable limited surround condition. In the present experiments, two orders of presentation were employed for three surround conditions. The annular border, which was expected to produce the most favorable condition, was always presented second. If the effects of successful practice under one condition are carried over, or generalized, to subsequent conditions, then one would expect performance under either the limited surround condition (SA-2, least favorable) or the full screen condition (SA-1) to be better when presented last than when presented first. This interpretation is consistent with the observation of a relatively large SA-1 by SA-2 interaction when SA-2 was presented first (Subjects SA, WC), and a relatively low interaction when SA-2 was presented last (WJ, DW, SJ). Also, it allows one to reconcile the anomalously superior performance of Subject WJ under the limited surround condition when this condition was presented last.

The present experiments have demonstrated that relatively simple modifications of the stimulus configuration in the target surround can affect significantly an individual's DVA performance. These results are relevant to the question of the adequate stimulus for visual acquisition and to the problem of standardization of DVA tests. Not all subjects responded to modifications of the target surround in the same manner. These variations among subjects may represent true individual differences, or they may reflect a confounding influence of practice and order effects. Subsequent experiments will be directed at determining whether practice effects may produce differences of this magnitude, and at observing the effects of practice under one surround condition upon performance under another surround condition.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Tests of dynamic visual acuity (DVA) appear to offer unique potential for assessing practical visual capabilities. These tests have not been standardized with respect to variations in the target surround, nor are the effects of such variations understood. Goodson and Morrison have demonstrated the ease with which the DVA function may be accelerated (increased degradation as a function of target velocity) by limiting the size of the target surround. According to their acquisition hypothesis, the DVA function should be decelerated by surrounding the target with a border. The problem is to determine whether DVA

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) performance may be degraded or enhanced by such manipulations of stimuli surrounding the acuity target.

The present experiments demonstrated that relatively simple modifications of the stimulus configuration in the target surround can affect significantly an individual's DVA performance. However, not all subjects responded to modifications of the target surround in the same manner. Implications regarding individual differences versus practice and order effects are discussed.